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Space Shuttle Return-to-Flight Re-Design Effort Solid Rocket Booster Bolt Catcher

**NASA's Marshall Space Flight Center
and
United Space Alliance, LLC**



Bolt Catcher Re-Design Team Members

Marshall Space Flight Center

- MSFC is design responsible for Space Shuttle Propulsion
 - Solid Rocket Booster (SRB)
 - Reusable Solid Rocket Motor (RSRM)
 - External Tank (ET)
 - Space Shuttle Main Engine (SSME)
- MSFC's Engineering Directorate has substantial in-house test capabilities
 - Dynamic Pyrotechnics Testing
 - Vibration and Acoustic Testing
 - Hot Gas Test Facility

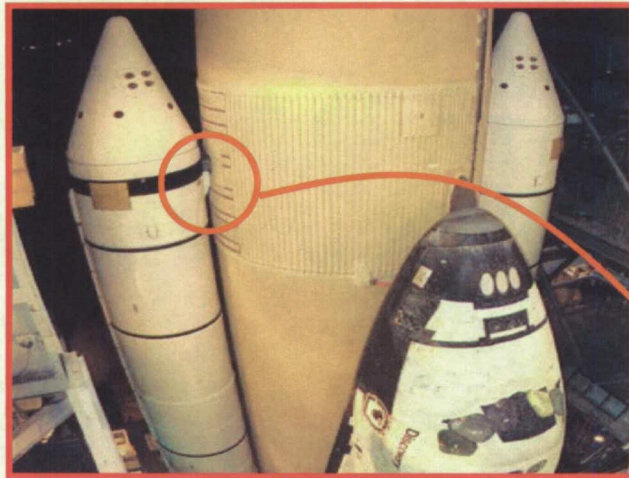
United Space Alliance, LLC

- NASA's Prime Contractor for the Space Shuttle Program
 - Design responsible on the Solid Rocket Booster Project
 - Team Lead on SRB Bolt Catcher Re-Design Effort

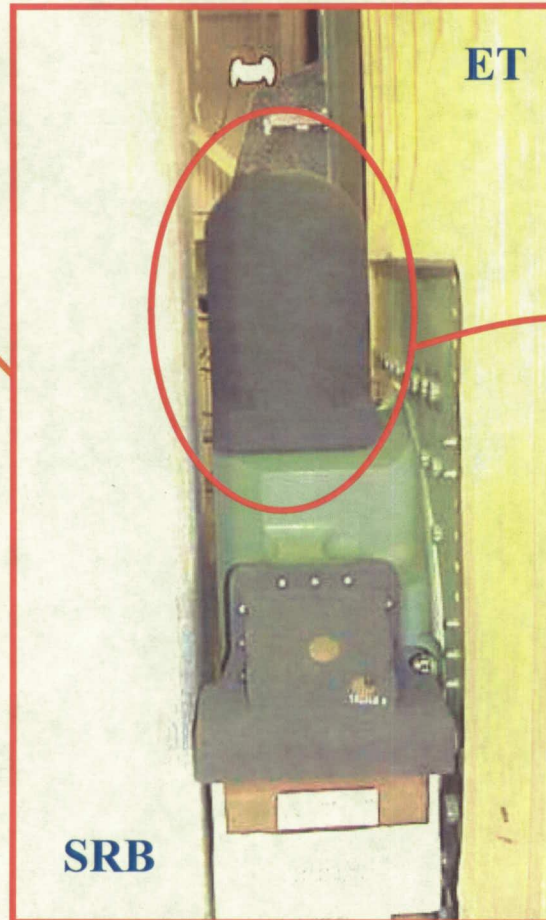
Columbia Accident Investigation

- **Immediately following the STS-107 Columbia Accident, NASA began a comprehensive investigation into its cause**
 - All credible debris sources were evaluated
 - The ET Bolt Catcher could not immediately be exonerated
 - An extensive review of the ET Bolt Catcher certification versus operational environments was initiated
- **Based on investigation a re-design was recommended**

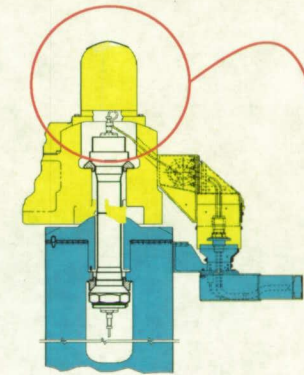
Bolt Catcher Orientation



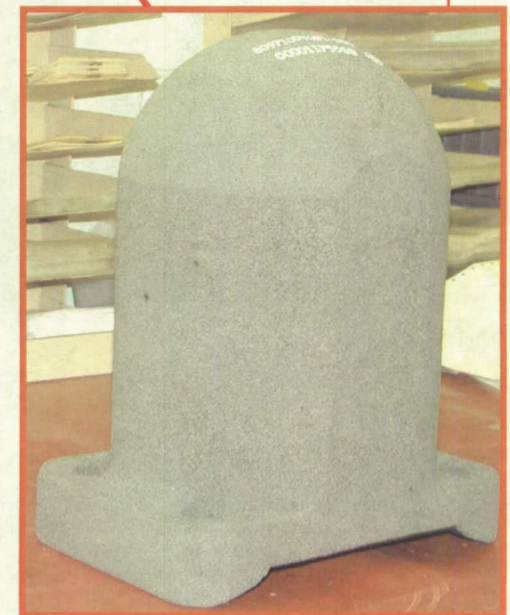
SRB – ET – Orbiter Stack



ET – SRB Mate



Cross-Section



Bolt Catcher Original Design and Testing

Original Bolt Catcher Qualification Testing

- **Bolt Catcher structural Qualification Test configuration was not fully representative of flight configuration.**
 - Flight attach fasteners and inserts not used in 1979 Qualification Test series at MSFC
 - SLA insulation was not included in SRB Qualification Tests
 - Thermal environment not included in Qualification Tests
 - Qualification part was forged - the pre-Columbia design is spin formed (that part has improved mechanical properties and was qualified by analysis/similarity)
 - NSI ejection is a known random event, but this pressure loading was not included in the original Qualification Tests

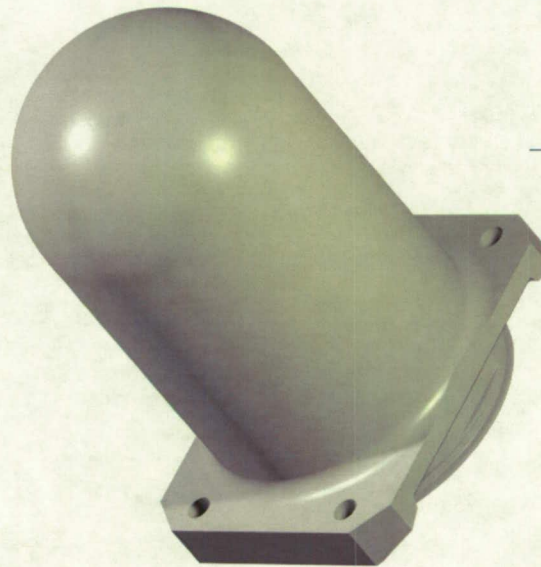
Design Review Findings and Recommendations

- **STS-107 Accident Investigation determined that the “existing” Bolt Catcher did not meet structural design requirement of 1.4 factor of safety**
- **Re-design recommended in the STS-107 Investigation Report**

Bolt Catcher Structure Re-Design

Pre-Columbia Structure Design

- The Bolt Catcher Structure consists of two pieces welded together
 - The two pieces are the Flange and the Dome
 - The Flange is made from 2219-T37 or 2219-T87
 - The Dome is Spin Formed in the 2219-T47 condition
 - The welded assembly is heat treated per MIL-STD-6088 to yield an average material ultimate strength of 42 KSI and a minimum material ultimate strength of 40 KSI
- The cylindrical wall and dome sections have a thickness of 0.125 inches



Re-Designed Structure Design

- The Bolt Catcher Structure is machined from a 7050-T74 or a 7050-T7452 Forging.
 - The forging has a minimum average ultimate strength of 64 KSI
- The cylindrical wall and dome sections have a thickness of 0.25 inches
- The new bolt catcher design has an integral O-Ring carrier built into bolt catcher structure

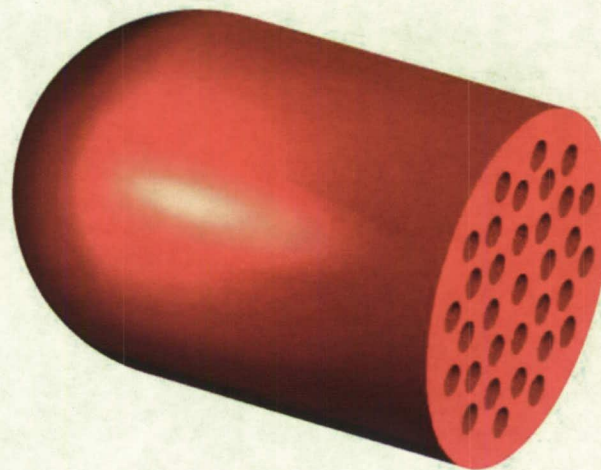
Bolt Catcher Energy Absorber Re-Design

Pre-Columbia Energy Absorber Design

- The Bolt Catcher Energy Absorber is made of 5052 Aluminum Alloy
 - The average static crush strength is 1400 PSI $\pm$ 10%
 - 33 holes are then drilled 6.91 $\pm$ 0.060 inches in depth, thus reducing the average static crush strength of the energy absorber to approximately 1000 PSI

Re-Designed Energy Absorber Design

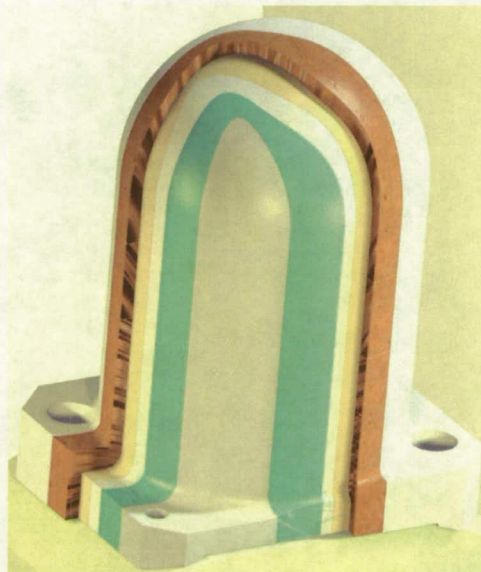
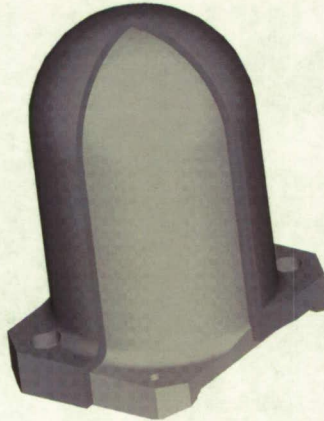
- The Energy Absorber material is Aluminum 5052A Grade B per MIL-C-7438
 - The average static crush strength may range from 746 to 910 PSI. This is based on the desired strength of 828 PSI $\pm$ 10 percent



Bolt Catcher Thermal Protection Re-Design

Pre-Columbia Bolt Catcher Thermal Protection

- SLA-561 is hand applied to a thickness of 0.60 ± 0.05 inches in all areas on the outside surface except sides of the flange where the chamfers are located.
- These Thermal Protection System (TPS) dimensions are governed by ICD-2-24001.

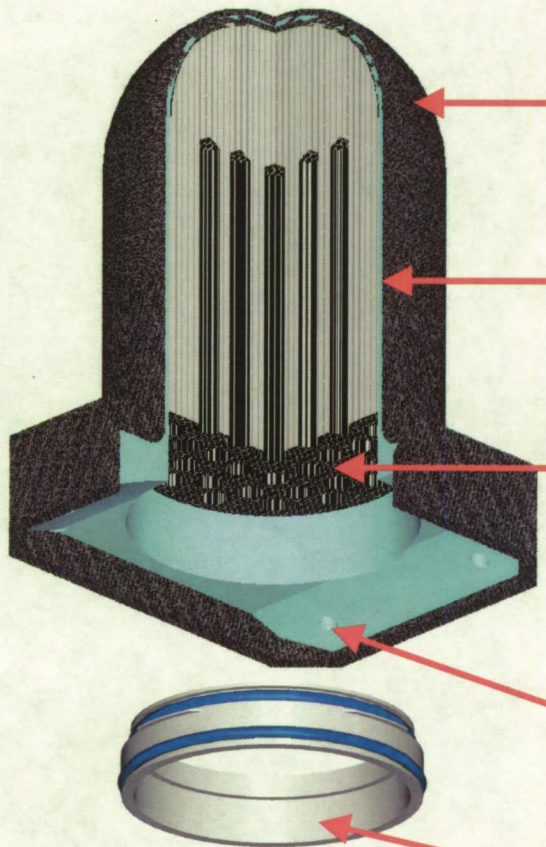


Proposed Insulated Bolt Catcher

- The Insulated Bolt Catcher consists of the following layers of insulation and protective finish:
 - Aluminum 7050 Bolt Catcher Structure [Grey]
 - Primer [Green]
 - Topcoat Paint [White]
 - Adhesive to bond the machined cork pieces [Yellow]
 - Cork applied [Brown]
 - Hypalon Sealcoat Paint [White]
- All protective coatings and cork are already certified and are used in similar applications on the SRB

Bolt Catcher Assembly Re-Design

Previous Bolt Catcher Design



TPS Material

SLA-561
Machined Cork

Housing

2 pc.; 2219 Al; 1/8 in. thick
1 pc.; 7050 Al; 1/4 in. thick

Energy Absorber

Spiral Wound 5052 Al;
1400 psi crush
5052 Al Honeycomb;
828 psi crush

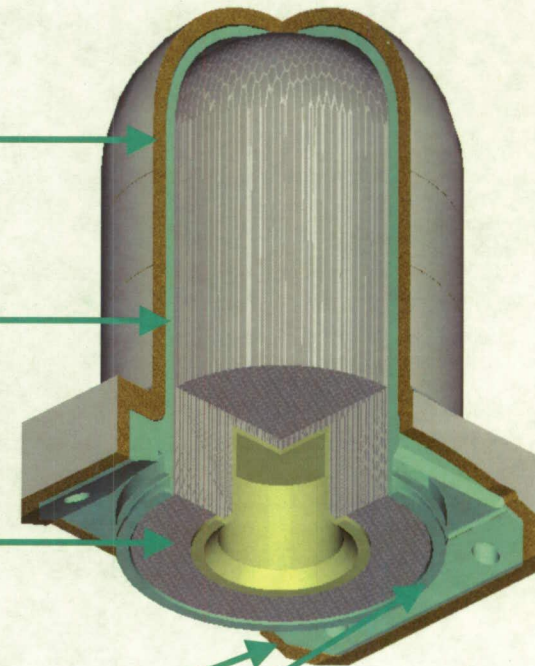
Fasteners

A286; 3/8 in.; 180 ksi
MP35N; 9/16 in.; 260 ksi

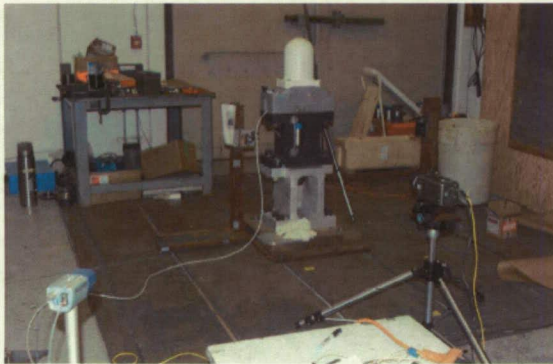
O-Ring Carrier

Separate
Integrated

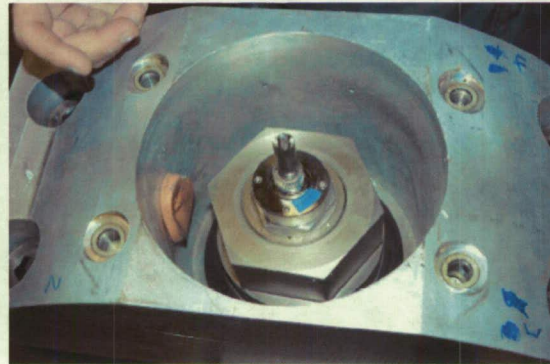
Re-Designed Catcher Design



Bolt Catcher Re-Design – Pyrotechnic Shock Testing



Test Set Up at MSFC PSF

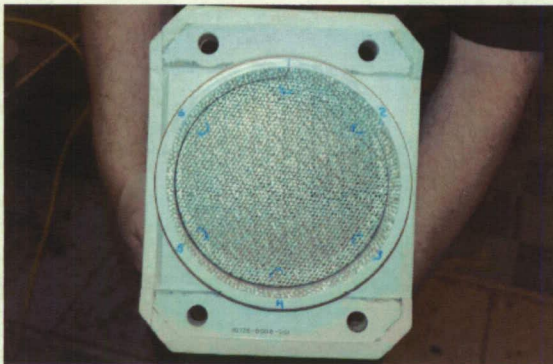


Separation Bolt Test Fixture - ET

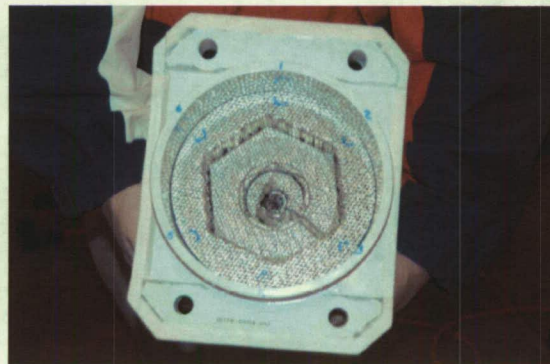


Assembled Bolt Catcher- Pre Test

- **MSFC Testing**
 - Pyrotechnic Shock Facility
 - Structural and Dynamics Testing Group
- **Test Results – Head / Nut velocities and penetration**
 - Test 1: 70.6 / 67.4 fps with 1.782 and 0.508"
 - Test 2: 73.8 / 67.5 fps with 2.164 and 0.775"



Energy Absorber – Pre Test

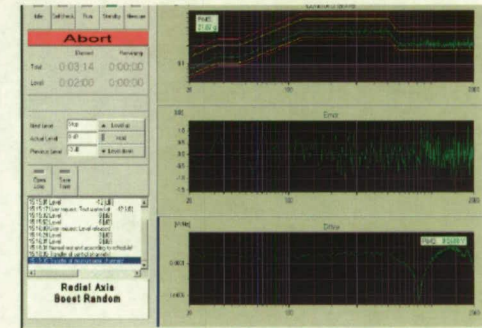
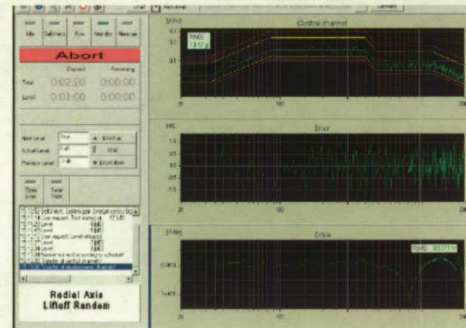
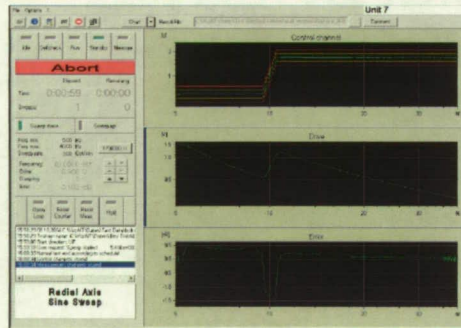


Energy Absorber – Post Test

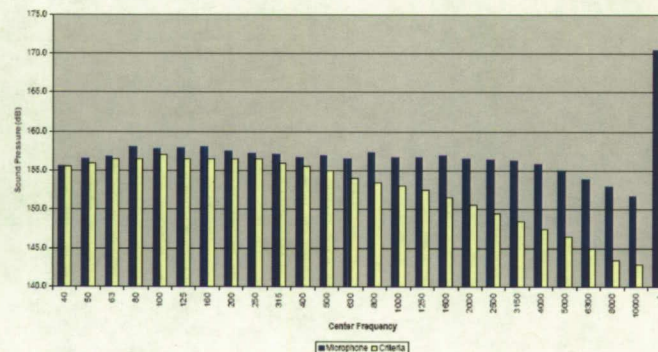
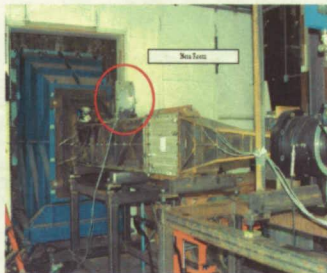


SRB Energy Absorber – Post Test

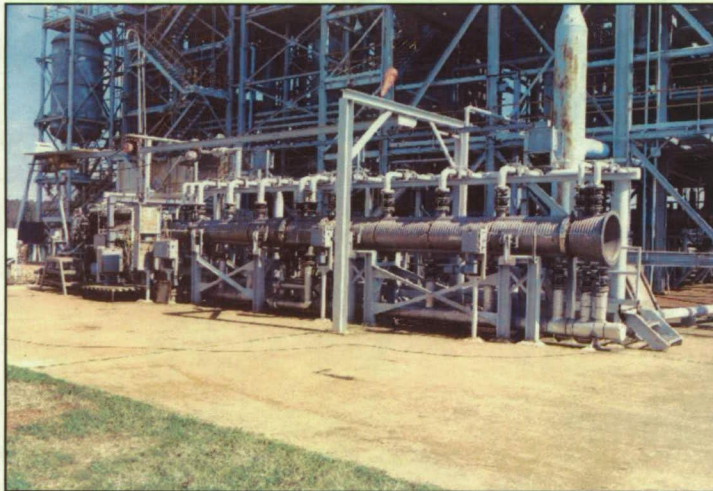
Bolt Catcher Re-Design – Vibration and Acoustic Testing



- **MSFC Testing**
 - East Vibration Facility
 - Structural and Dynamics Testing Group
- **Test Loads in Radial, Longitudinal and Tangential Axis**
 - Swept Sine (Vehicle Dynamics)
 - Lift-Off Level Random
 - Boost-Level Random
- **MSFC Testing**
 - Acoustic Test Facility
 - Structural and Environmental Test Division
- **Acoustic Levels**
 - In-Flight levels exceed Lift-Off levels
 - Tested at in-flight levels for the duration of lift-off and flight (enveloping)



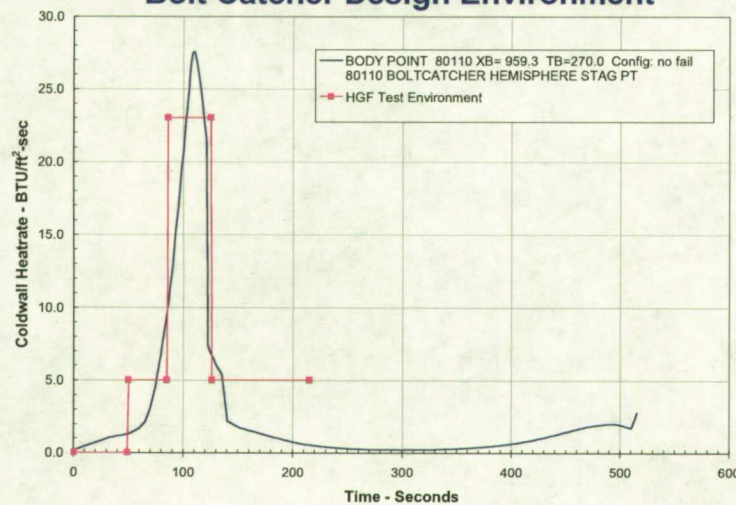
Bolt Catcher Re-Design – Hot Gas Qualification Testing



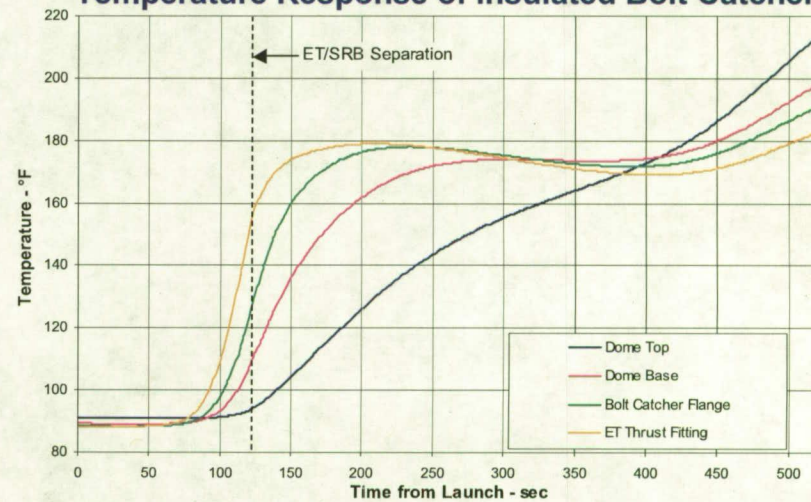
MSFC's Improved Hot Gas Test Facility

- MSFC manages a one-of-a-kind aero-thermal test facility that can emulate many of the Space Shuttle design environments
- USA, LLC has a long history of test activity in that facility for the SRB Project
- The Bolt Catcher underwent the most comprehensive series of tests ever performed in the MSFC dynamic test facilities

Bolt Catcher Design Environment



Temperature Response of Insulated Bolt Catcher



Bolt Catcher Re-Design

First Flight of the Newly Re-Designed Bolt Catcher



Mission: STS-114 – ISS Assembly Mission LF 1
Launched: July 26, 2005, 10:39:00:07 a.m. EDT
Launch Pad: 39B
Orbiter: Discovery

S114E5070